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Reviewing Different Types of Working Memory Training on Reading Ability Among Children with Reading Difficulties

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ABSTRACT

This review evaluates the effectiveness of different types of working memory training on reading performance among children with reading difficulties. Reading performance is closely related to academic achievement whilst working memory (WM) serves as a crucial cognitive component to reading. Some researchers believe that WM training can improve WM capacity, intelligence and other cognitive functions. However, whether the effect extends to reading performance has rarely been examined. According to the multi-component WM model, the current review classifies WM training into domain-general, domain-specific (verbal WM and visuospatial WM), and mixed training and evaluates their effectiveness to reading ability correspondingly. According to the existing studies, verbal WM training seems to be most effective for improving reading ability, while other types of training show effects on WM or cognitive skills but only limited effects for reading. Limitations of these findings and reasons for transfer failure are discussed.

KEYWORDS

reading difficulties; learning difficulties; working memory training; reading; brain training

Introduction

Twenty years ago, Klingberg et al. (2002) first claimed that working memory (WM) training enhances the intelligence of children with attention deficit and hyperactivity disorder (ADHD) and young adults without ADHD. The debate on whether WM training can benefit children's academic performance has not yet reached a consensus (e.g., Melby-Lervåg & Hulme, 2013; Shinaver et al., 2014). Some researchers argue that short-term WM training positively affects both trained and untrained WM tasks (Klingberg et al., 2005; Peng & Fuchs, 2017; Shinaver et al., 2014) and even transfers to other fluid intelligence (Au et al., 2015; Jaeggi et al., 2008) and academic performance (Shinaver et al., 2014). Other researchers argue that WM training only results in a short-term specific effect on trained WM tasks but cannot generalize to other cognitive tasks or "real-life" skills, for example, reading (De Simoni & von Bastian, 2018; Melby-Lervåg et al., 2016; Melby-Lervåg & Hulme, 2013). This review addresses WM training and its relation to reading performance in children with reading difficulties.

Fluent reading is essential to acquiring knowledge and academic attainment (van den Broek & Espin, 2012). Through reading, children build up basic knowledge about the world and subject-specific expertise. Unfortunately, not all students can acquire adequate reading skills naturally. About

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3 – 10% of school-age children suffer from reading difficulties (Snowling, 2013) which is a commonly seen learning difficulty. Children with reading difficulties have difficulties in processing written texts, including recognizing words and comprehending sentences. A shared characteristic of children with learning difficulties is low WM capacity (Ashkenazi et al., 2013; Menon, 2016). Therefore, if WM training improves WM capacity, as Klingberg (2010) suggests, intuitively, children with low WM capacity have more room to improve. Thus, WM training might yield a positive outcome for their WM capacity and reading performance. Nevertheless, Melby-Lervåg et al. (2016) reported in their meta-analysis that WM training improved similar WM task performance among children with reading or other learning difficulties, but the effects can neither maintain for a long time nor transfer to cognitive or academic abilities.

Given the current debate on the effectiveness of WM training on reading, we will review existing WM training programs containing reading measurements under a classic multi-component WM model framework (Baddeley, 1986). The framework contains four components, including central executive, visuospatial sketchpad, phonological loop and episodic buffers. We selected primary studies based on their training, assessment and participants: (1) contain working memory training components; (2) adopt reading assessment in pretest and posttest; (3) focused on children/young adults with reading difficulties or learning difficulties. We also include studies that focus on participants with learning difficulties because reading difficulties are specific types of learning difficulties. 15 primary studies were identified through this process. Then we will further explain why some WM training programs yield limited enhancement in reading abilities while others show both promising near-transfer effects on similar WM tasks as well as considerable far-transfer effects on reading among children with reading difficulties.

The Nature of Working Memory

WM is an essential component in human cognition (Daneman & Carpenter, 1980). WM is indexed by the ability to complete complex span tasks that simultaneously require storing and processing temporary information (Baddeley, 1986), such as remembering items while presenting and conducting mathematical operations simultaneously. WM is a reliable predictor of other cognitive abilities such as general fluid intelligence (Engle, 2002) and thinking ability, including reasoning, comprehension and problem-solving (García-Madruga et al., 2016). It is also related to academic attainments such as reading (Daneman & Carpenter, 1980; Engel de Abreu et al., 2011) and mathematical abilities (Alloway & Passolunghi, 2011; Ashkenazi et al., 2013; Menon, 2016). For instance, WM at the age of five predicts literacy and numeracy at 11 years old (Alloway & Alloway, 2010). Moreover, individuals with high WM have better attention control (Engle, 2002; Unsworth & Spillers, 2010) and are less mind-wandering (Kane et al., 2007). Therefore, children with lower WM might experience more obstacles in reading because they are less able to hold relevant information when encountering interference and distraction (Engle et al., 1999).

According to the multi-component WM model, there are four components in the WM system (Baddeley & Hitch, 2019). The first is the central executive, which serves as a general attentional control system that supervises and coordinates the whole process. The two short-term memory storage systems: visuospatial sketchpad and phonological loop, constitute the second and third components of the model. They coordinate input information from different sources. Specifically, the visuospatial sketchpad retains visual features such as colors and shapes, spatial features such as locations, and haptic elements such as kinesthetic and tactile information. It is usually measured by tasks that entail memorizing the locations of shapes or letters (Holmes et al., 2008). The phonological loop coordinates linguistic information from speech, music or sign language. It is usually measured by verbal digit span (Woods et al., 2011), whereby participants need to remember digits and repeat them forwards or backwards. The primary function of the visuospatial sketchpad and phonological loop is storage but not processing. The fourth component, episodic buffer, could process multimodal information from different sources and is introduced to combine visuospatial and verbal information. Furthermore, the episodic buffer can extract the long-term memory to incorporate into short-term storage.

These four components can be classified as domain-general and domain-specific components. Domain-general components include the central executive and episodic buffer that process all kinds of information. Domain-specific components are the phonological loop (verbal WM) and visuospatial sketchpad (visuospatial WM) that process domain-specific information. WM deficits among individuals with learning difficulties manifest as domain-general constraints (i.e., poor in controlling attention processing) and domain-specific constraints (i.e., inefficiency in processing phonological information) (Swanson & Siegel, 2011). Furthermore, children with learning difficulties show asymmetric abilities among two domain-specific components. For example, children with mathematical difficulties show more visuospatial and numerical WM deficits, while children with reading difficulties show more deficiencies in the verbal WM domain (Peng & Fuchs, 2016; Swanson, 2006; Swanson et al., 2009). As such, WM deficits can be subtyped according to WM components.

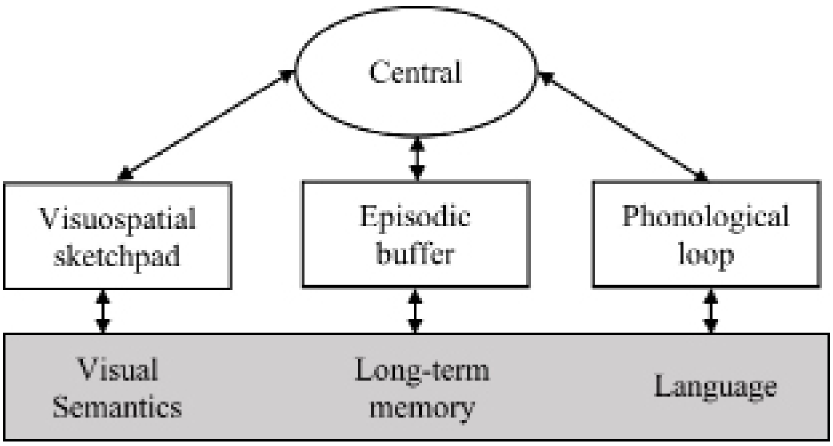

Figure 1. *The multi-component WM model (Baddeley, 2000)*

Reading, Reading Difficulties and Working Memory

The ultimate goal of reading is comprehension, which requires skilled word decoding and linguistic comprehension (Gough & Tunmer, 1986). Visuospatial and verbal WM plays a vital role in decoding words: visual letters are converted to sounds and sequentially enter the WM system and are stored until all letters are combined as a word (Titz & Karbach, 2014). To comprehend, verbal WM retains new language information whilst the episodic buffer connects new information to prior knowledge and thus constructs and integrates the overall representation of the text materials.

The relation between reading and WM should be seen from a developmental point of view. For skilled readers who can recognize words effortlessly, their WM resources are allocated more to the language comprehension process than decoding (Peng et al., 2018) because their word recognition becomes automatic. Therefore, reading relies more on verbal WM than visuospatial WM (Peng et al., 2018). By contrast, for younger children or students with reading difficulties, it takes great effort for them to retrieve phonological representations and find vocabulary information from the mental lexicon (Savage et al., 2007; Swan & Goswami, 1997). Therefore, reading relies more on domain-general

WM (Peng et al., 2018), because recognizing individual words and word meanings is more effortful for emerging readers.

Children with reading difficulties show a common deficit in various WM measures (Gathercole et al., 2006; Maehler & Schuchardt, 2009; Swanson et al., 2009) at both domain-specific and domain-general levels. At the domain-specific WM level, children with reading difficulties perform consistently worse than typically developing children in verbal WM tasks but not necessarily in visuospatial tasks (Swanson et al., 2009). At the domain-general level, they lack attention control and WM strategies, including rehearsal, updating and binding. Without good attention control, poor reading comprehenders are less able to differentiate between important and less-important information and focus on the more important inputs. For WM strategies, children who rehearse less have a shorter retention duration (O'Shaughnessy & Swanson, 1998). In addition, poor reading comprehenders perform poorly in word updating tasks (Cornoldi et al., 2012) which require participants to identify the three smallest objects from a list of objects. They also have a lower ability to bind verbal and visual stimuli (i.e., binding shape to nonword), suggesting a poor cross-modal WM (Garcia et al., 2019; Toffalini et al., 2019).

Poor WM limits the ability of children with reading difficulties to retain information in mind and resist disturbance from unnecessary stimuli (Swanson & Jerman, 2007). To fully understand the texts, students need to extract the meanings of every single word from their vocabulary storage and then form them into a semantically understandable sentence. They also need to actively summarize the immediate text and integrate it with previous content and background knowledge (Kintsch & Welsch, 1991). Students cannot comprehend well if they fail to retain the previous text and combine it with new information because of low WM capacity. So, gradually, they lag behind their cohorts and have poor comprehension skills and academic performance (Gathercole et al., 2006; Peng & Fuchs, 2016). In sum, the general processing deficit in maintaining, updating and binding information and the specific deficit in verbal WM impede children's reading ability.

Working Memory Training

Some researchers believe that WM capacity is flexible, and it can be improved by intensive training (Gathercole et al., 2006; Shipstead et al., 2012). WM deficit is a fundamental impediment that prevents children with reading difficulties from fulfilling their academic potential (Swanson & Siegel, 2011). Increases in WM capacity might make it easier for them to take up higher WM-demanding tasks that are related to reading. For example, if children with reading difficulties can hold more verbal information or retrieve semantic knowledge from their long-term memory faster, they can read more fluently and accurately. Given this, it is worthwhile to explore whether WM training can improve reading performance or not.

WM training can yield near- or far-transfer effects. The near-transfer effect is quantified as WM training results in the improvement of untrained WM tasks, while the far-transfer effect is the improvement of other cognitive abilities and academic performance such as IQ and reading skills (e.g., Gropper et al., 2014; Shipstead et al., 2012). Previous research has found a small-to-medium near-transfer effect immediately after training and in the long run, a small far-transfer effect on cognitive abilities, no far-transfer to academic achievement in children with ADHD (Simons et al., 2016) and no significant far-transfer effect on verbal skills compared to untreated control groups (Melby-Lervåg et al., 2016). It seems that previous studies do not support the idea that WM training can have far-transfer effects on reading ability.

However, the null effect might merely be due to the wrong type of training protocol or paradigm. No consensus has been reached on which WM component deficit is the primary reason impeding reading development (Savage et al., 2007). Some researchers argue that the domain-general WM deficit in processing and storage results in poor reading (de Jong, 1998). Others propose that verbal WM storage shortage serves as the bottleneck to reading comprehension (Jorm, 1983). Whether dyslexic children with verbal WM deficits would improve after receiving visuospatial WM training remains to be investigated. Therefore, to evaluate whether WM training is useful at all, we classified different ways of training WM before we assessed the effectiveness of each of them.

In the current review, in line with the multi-component WM model, we categorized WM training into three types according to the training tasks: domain-general, domain-specific (verbal or visuospatial) and mixed training. Some research studies focus on domain-general training (Chen et al., 2018; St Clair□Thompson et al., 2010; Swanson et al., 2010) to improve general processing ability, which is critical for doing various tasks. Other studies only focus on one specific domain, such as verbal WM or visuospatial WM (Peng & Fuchs, 2017; Wang et al., 2021). Others use a mixed method to train two domain-specific components simultaneously (Dahlin, 2011; Yang et al., 2017). Additionally, we also included some recent studies that move WM training outside the laboratory and integrate them as part of a school project to foster reading ability and academic gains (Carretti et al., 2014; García-Madruga et al., 2016). Although there are also several types of training that affect working memory capacity, including mindfulness training (Mrazek et al., 2013), neurofeedback (Wang & Hsieh, 2013), and motor exercise (Koutsandréou et al., 2016), we only focus on training studies that target WM specifically.

Domain-General WM Training: Central Executive and Strategy Training

Domain-general training targets improvements in the central executive functioning while processing information. Strategy knowledge is a crucial domain-general ability in children's WM development. Strategy training such as rehearsal, clustering, association and elaborating facilitates children's central executive functioning efficiency in encoding, maintaining and retrieving information. Children with reading difficulties usually have unstable strategy choices, which can reduce processing efficiency (Swanson et al., 2010). Whether strategy training can benefit their central executive functioning and reading will be discussed in this section.

Although strategy training seems to yield a significant training effect on the WM component, previous training studies found no effect in far-transfer to other tasks. For example, rehearsal training can improve typically developing adults' verbal WM and passage comprehension (Turley-Ames & Whitfield, 2003). However, it might not be as effective in children with reading difficulties. In a study by Swanson et al. (2010), 29 children with or without reading difficulties (10 – 11 years) received 10 to 15 minutes of rehearsal instruction, during which they were taught to repeat the material aloud as many times as possible. In the immediate post-test, children with reading difficulties gained more item recall than those without, suggesting strategy training helps children with reading difficulties allocate WM resources more efficiently. However, the improvement of WM did not transfer to gains in listening span performance, which is a task that requires students to comprehend the sentence and then recall the last words of a series of sentences (Swanson et al., 2010). This finding seems reasonable as the training lasted only 15 minutes; children, especially those with reading difficulties, may not master the new strategy immediately. They may need more time to integrate new strategies into the reading process before they can use them comfortably. Concludingly, we argue that a short training session is not sufficient for WM improvement, which limits conclusions about the effectiveness of domain-general WM training drawn from this study. Moreover, even if training did improve WM capacity, far-transfer to reading achievement requires more time before it can be seen (Shipstead et al., 2012).

Elaborate encoding training is another domain-general training involving strategies such as grouping, mental imagery and creating stories. A study that included some children (5 - 8 years) with special education needs explored the effect of elaborate encoding training (St Clair□Thompson et al., 2010). Children in the intervention group were guided to use rehearsal and visual imagery strategies to memorize story elements and then actively create new stories to help memorize them. The training duration was 30 minutes per day for six to eight weeks. Although the encoding training group gained more in the verbal WM and mental arithmetic task than the control group, they did not show far-transfer to standardized reading and mathematics tasks in the post-test or five-month follow-up.
Updating training is a type of central executive training that increases the neural activity in the striatum along with reduced activity in frontoparietal networks (Dahlin et al., 2008), indicating more automated general processing. 54 children with learning difficulties (10 – 11 years) participated in either 20 days of updating training or no training (Chen et al., 2018). In the training group, children had to remember several animals, letters and locations without being told how many items to hold, so they updated their memory constantly. Although the training group showed improvements in verbal WM and nonverbal reasoning while the control group did not, their reading ability (Chinese exam score) did not improve significantly. Similarly, another WM updating training only found a transfer effect to mathematical ability but not reading ability in seventh-grade students (10 – 13 years) with learning difficulties (Zhang et al., 2018).

In sum, strategy training is a type of domain-general training which is designed to strengthen central executive functioning. None of the abovementioned strategy trainings show any transfer to reading performance. Moreover, the effect could not even transfer to less-similar WM tasks that use different strategies or test materials. The lack of far-transfer effect appears to address the limitation of strategy training: the generalizability of novice learners is limited to the similarity of task materials and the required strategies. Younger learners or those with learning difficulties still find it difficult to generalize the learned strategies from one domain to another (Brown, 1982). Therefore, domain-general training only has a small effect on reading abilities.

Domain-Specific Training: Verbal and Visuospatial Working Memory Training

Verbal WM is a strong predictor of reading performance (Pham & Hasson, 2014). Impaired verbal WM hinders phonological processing ability, such as blending and segmenting phonemes, and thus it sets constraints on word decoding ability.

Only two studies focus on verbal WM training in children with or showing early traits of reading difficulties to our knowledge. The first study compares 58 first-grade children (7 years) at risk of learning difficulties who received a) verbal WM training only, b) verbal WM combined with rehearsal instruction, or c) no treatment (Peng & Fuchs, 2017). Children received 10 35-min one-on-one training sessions over 10 days, which included four complex verbal WM tasks in each session that required children to solve problems and answer verbally. In the rehearsal combination group, children learnt to use a rehearsal strategy by saying the selected words aloud and repeatedly accompanied by verbal WM training. Children who received rehearsal and verbal WM training gained significantly more in untrained verbal WM and passage listening comprehension tasks than the control group. Children who received only verbal WM training also outperformed the control group in passage listening comprehension. The results support that verbal WM training – especially accompanied by strategy training – can strengthen reading skills as it helps improve comprehension. However, the study suffered from underpowered analyses because of the small sample size (19 to 20 students in each group). While this offers a promising result for verbal WM training, more studies should be done to examine the effectiveness of verbal WM training on a larger scale.

Another study compared verbal WM training (phonological n-back) and visuospatial WM training (visuospatial n-back) in children with dyslexia aged 9 - 10 years (Yang et al., 2017). The n-back paradigm is a widely used WM task adopted by Jaeggi et al. (2008) as a training program. It requires participants to process a series of stimuli and indicate whether the current stimulus matches the one presented in n trials before. In the verbal WM training group, children received 15-min phonological n-back training sessions per day for 15 days. The stimuli in the phonological n-back training group were six Chinese vowels. In the visuospatial training group, the training procedure was identical to the phonological training group, except that the training materials were visuospatial dots.

Compared to a passive control group, children who received verbal WM training had higher accuracy in phonological awareness and decoding fluency at post-test, but they did not show any difference in visual-orthographic awareness. By contrast, children who received visuospatial WM training did not improve more in phonological awareness tasks in the post-test than controls, but there was an interaction effect suggesting they performed better than controls in visual-orthographic awareness and decoding fluency in the post-test.

The results demonstrate that the transfer between similar types of stimuli is more common than the transfer between different types. When children receive adequate verbal training, they are more likely to improve in verbal tasks. Similarly, when children receive training that uses visual stimuli such as characters or images, they are more likely to enhance their visual-orthographic ability. The results indicate that verbal and visuospatial WM training can help improve metalinguistic skills in different ways and then enhance decoding ability.

In a nutshell, previous findings support that verbal WM training helps poor readers improve their phonological WM and reading performance, although one study is slightly underpowered. Training can strengthen verbal WM's ability to hold and process phonological information, and thus it also has a far-transfer effect on reading ability. Visuospatial training, on the other hand, improves children's visual ability so that they are more aware of the orthography of words. However, we cannot ignore the limitation of previous studies, either small in sample size or using a passive control group. We need more rigorous experimental designs to draw a more definite conclusion about the effectiveness of domain-specific WM training on children's reading ability.

Mixed Training (Combined Verbal and Visuospatial)

Combining various WM training tasks can increase students' motivation and foster transfer effects in a different context (von Bastian & Oberauer, 2014). Therefore, mixed training is often favored by researchers or commercial programs. For example, a well-known commercial program Cogmed (Shipstead et al., 2012), consists of 12 verbal and visuospatial WM tasks. Some research has found that Cogmed showed a positive training effect on WM tasks and a long-term impact on reading ability in typically developing children (for a meta-analysis, see Söderqvist & Bergman Nutley, 2015). In contrast, others did not find a far-transfer effect on academic skills (for a meta-analysis, see Aksayli et al., 2019).

Three studies have evaluated the Cogmed training effect in individuals with reading difficulties or severe learning difficulties. Dahlin (2011) compared the outcomes of upper elementary-school children (9 – 12 years) with learning difficulties who received training (n = 42) and their untrained counterparts (n =15). Children in the training group received daily 30-min computerized verbal and visuospatial training for 20 to 25 days. Compared to an active control group, children who received the training showed near-transfer in verbal WM processing and storage and visuospatial WM. There was also a far-transfer to reading comprehension immediately after training which was maintained for six months, despite there being no effect on decoding or orthographic skills. The results seem to suggest that mixed verbal and visuospatial training serves as remediation for poor reading comprehension. However, a major deficit of that study is that the control group is not homogeneous but borrowed from another study that targeted children with ADHD (Klingberg et al., 2005), making the result less reliable.

The second study (Gray et al., 2012) compared mathematics training with the Cogmed WM training program in 60 teenagers (12 – 17 years) with comorbid ADHD and severe learning difficulties. The training was conducted four to five times per week, 45 minutes each, for five weeks. Children who received WM training gained more in verbal WM than the mathematics training control group but did not show any far-transfer to academic achievement in either decoding or comprehension. Another Cogmed training program (Gropper et al., 2014) was evaluated with college students (28 years) with learning difficulties. Students who received intensive WM training over five weeks gained significantly more than the passive control group in trained WM, but there was no group difference in training effects on untrained WM or reading fluency. The main limitation of this study is that 38% of the participants in the experimental group did not complete follow-up tests, which resulted in underpowered analysis.

Three studies shed light on other mixed WM training programs in children or young adults with dyslexia, yielding no transfer effect to language components. A six-week training program containing 18 45-min sessions consisted of 30% verbal short-term memory (STM) training games, 20% visuospatial STM training games and 50% central executive training games. The training did not result in any improvement in either near-transfer or far-transfer among 139 third graders (8 - 9 years) (Maehler et al., 2019). In another six-week mixed WM training ("CogniFit") program (24 15-min sessions, total duration: 6 hours), 41 undergraduate students (25 years) with dyslexia also did not show significant improvement in word reading, pseudoword reading or reading comprehension (Shiran & Breznitz, 2011). The third study comparing mixed WM training and meta-linguistics skills training in second and third-year elementary-school children (mean age = 8.4 years) with dyslexia showed that both groups significantly improved on the word reading task, but only the meta-linguistic training group gained more syllable awareness (Wang et al., 2021). However, because of the lack of an active control group, we cannot infer whether the growth in word reading ability was due to training or the regular class curriculum. Also, there was no positive effect on syllable awareness in the WM training group, indicating that WM training and meta-linguistic training target different aspects of the reading process.

In sum, it is evident that most existing mixed training programs do not have a promising far-transfer effect on any reading achievement. The only study that claimed to show some enhancement did not include an active control group (Wang et al., 2021). The results of mixed training programs seem to contradict the findings from domain-specific training. If verbal WM alone could improve reading performance, mixed training that contains verbal WM training should also be effective. Therefore, there might be other causes for the null effect. For example, either there were negative interactions between different types of training due to cognitive overload or some training programs were poorly executed in practice. Hence, we should be cautious when we explain these conflicting results because those intervention studies are heterogeneous in nature. They used very different samples with a wide range of ages and various medical conditions, for example, some with learning difficulties, and others having ADHD; some are elementary-school students while others are adults.

Working Memory Training Embedded in Academic Skills Training

The WM trainings mentioned above were all done in the laboratory. Some researchers have suggested that WM training conducted in a classroom setting showed positive outcomes and higher ecological validity. Although these programs were done among typically developing children, they might give us some insight into the reading difficulty group. For example, a classroom-based Cogmed intervention program involving 50 children (9 - 11 years) with low academic attainment showed a positive transfer effect in English using a standardized test (Holmes & Gathercole, 2014). Another intervention program applied in the fourth and fifth-grade classrooms targeted at typically developing children (9 - 11 years) also yielded significant improvements in reading ability (Carretti et al., 2014). The researcher inserted 10 minutes of verbal WM training (recalling verbal material) and metacognitive reflection into either a reading or listening comprehension training program. After 22 one-hour training sessions, children in the reading comprehension training group demonstrated larger gains in reading ability than children in the listening comprehension training group. The positive effect was maintained 11 months after training.

These findings support that integrating WM training might be effective in an inclusive classroom wherein children with low academic achievement and typically developing students receive an intervention jointly. The effect is also influenced by the training modality (Carretti et al., 2014). Text-based reading training might be more effective than listening comprehension training. Nevertheless, no existing study has focused on students with reading difficulties. Future research can examine the effectiveness of reading comprehension training combined with working memory training in this group.

Discussion

This review investigated the effect of WM training on reading ability in the scope of children with reading difficulties and examined whether different types of WM training according to the multi-component WM model yield different transfer effects. Despite WM being strongly related to reading skills and some training showing a transfer effect on untrained WM tasks, not all training programs show a far-transfer effect on reading ability. The far-transfer effect is rarely seen in domain-general or mixed training, but it is not uncommon in verbal WM training.

The present literature review suggests that verbal WM might be the most effective training method among different types of WM training. Two studies (Peng & Fuchs, 2017; Yang et al., 2017) demonstrate that verbal WM training positively affects decoding and listening comprehension within a relatively short period. As cognitive training serves as a method for new skills acquisition (Gathercole et al., 2019), the transfer effect manifests in the ability to apply the new skills to untrained tasks. Some children with reading difficulties have low cognitive abilities before training, so they are less likely to develop new skills or strategies within a short training period compared to typically developing children. However, the two verbal WM training programs reviewed have the shortest training periods yet yield positive results, indicating that appropriate short-term verbal WM training could be sufficient for developing transferable skills. Verbal WM training might also enhance children's abilities to hold phonological information. After repeated training, children can retain phonological information with less effort, and thus they can allocate more cognitive resources to process that information.

Still, we should be cautious when drawing the conclusion that verbal WM is more useful than the others. The training programs mentioned in the review have several limitations, including a small sample size, underpowered analyses and a passive control group. More research with a more rigorous research design should be done to investigate the effectiveness of verbal WM training on improving reading ability.

Most interventions presented in the current review failed to transfer to reading ability. There might be four reasons. Firstly, in strategy or central executive training, the far-transfer might reflect systematic changes in strategy choices (von Bastian & Oberauer, 2014). Short-term training cannot help children form a stable strategy choice. Even if children learn to adopt a new strategy in WM tasks, they cannot spontaneously transfer it to other materials or cognitive tasks. Therefore, interventionists should explicitly teach students how those strategies can be used in maintaining and processing information during reading. Additionally, future studies could monitor children's strategy choices before and after the intervention to examine whether they adopt more stable and appropriate strategies following the intervention.

Another explanation is that reading is a complex process which does not merely depend on cognitive abilities but also on linguistic skills (Kim, 2017). Language skills such as phonological awareness, syntactic awareness and inference skills explain large variances in reading performance. Even if WM processing or capacity improves after training, poor language skills and learning abilities caused by previous low WM set constraints on reading improvement. It takes time for WM improvement to transfer to other language skills or learning processes before progress in academic achievement can be seen.

The third possible explanation is related to the neural mechanisms of WM and WM training. Neural changes in WM related areas after training provide the foundation for transfer effects to other cognitive abilities that activate similar areas. WM tasks involve neural activities in frontoparietal networks whilst training increases the activities in the prefrontal cortex and the connectivity within the prefrontal cortex, and the connectivity between the prefrontal and other brain regions (Constantinidis & Klingberg, 2016). The reading network comprises a set of areas in the temporal (Broca's area), parietal (angular gyrus and precuneus) and frontal (attention control) lobes (Cattinelli et al., 2013). Specifically, the transfer effect is domain-specific and only occurs when the training and testing tasks have some cognitive components that involve overlapping cortical regions (Dahlin et al., 2008). The WM network and reading network only share some common regions in the attention control network, but domain-general WM training does not focus on attention control (but on processing or storage). Therefore, it is not surprising to see such little transfer effects from domain-general WM training to reading improvement. Lastly, the degree of transfer depends on similar structures, stimuli and paradigms between tasks (Gathercole et al., 2019). The transfer effect is restricted when trained by visual stimuli and tested by verbal materials. At the same time, the effect is more robust when transferring among different types of stimuli within the same scope. For example, in Peng & Fuchs's (2017) study, verbal training adopted the naming pictures and solving puzzles paradigm, which contained word and sentence-level verbal stimuli. The testing tasks used passage listening comprehension that included verbally presented sentences as well. When the training tasks and testing tasks use similar verbal material, transfer between them is more likely to happen. Therefore, children in that program demonstrated better performance in the listening comprehension task. Even though Cogmed training programs consist of verbal training, the materials used for training are letters or digits, which is very different from materials used in word recognition or reading comprehension tasks. Given that similar training and testing material is the key to a significant far-transfer effect, teachers should use verbal or text materials such as sentences if they want to apply WM training to the classroom. This is because it is easier for children to adopt new strategies in the reading process through similar materials.

Conclusion

The present review categorized four types of WM training using the multi-component model and evaluated their effectiveness in enhancing reading ability among children with reading difficulties. They are domain-general/central executive training (strategy training), two domain-specific trainings (verbal WM and visuospatial WM) and mixed training (combined different types of training), as well as WM training programs embedded in academic skills training.

Despite the close relation between WM and reading ability, the existing WM training programs only showed a limited impact on improving reading ability, if any. Among them, verbal WM training seems to yield the most significant training effect in enhancing reading performance, probably due to the close relation between verbal WM and reading development (Pham & Hasson, 2014). However, there were limitations in the studies of current training programs, for example, small sample sizes and short training periods, which means that we might not be able to draw any solid conclusion about whether WM training can improve reading ability. That said, we could learn from the existing studies and conduct further studies using verbal or text materials and more rigorous study designs to evaluate the far-transfer effects on reading.

References

Aksayli, N. D., Sala, G., & Gobet, F. (2019). The cognitive and academic benefits of Cogmed: A meta-analysis. Educational Research Review, 27, 229–243. https://doi.org/10/gjk2vq

Alloway, T. P., & Alloway, R. G. (2010). Investigating the predictive roles of working memory and IQ in academic attainment. Journal of Experimental Child Psychology, 106(1), 20–29. https://doi.org/10/cjfxwk

Alloway, T. P., & Passolunghi, M. C. (2011). The relationship between working memory, IQ, and mathematical skills in children. Learning and Individual Differences, 21(1), 133–137. https://doi.org/10/c59xv9

Ashkenazi, S., Rosenberg-Lee, M., Metcalfe, A. W. S., Swigart, A. G., & Menon, V. (2013). Visuo–spatial working memory is an important source of domain-general vulnerability in the development of arithmetic cognition. Neuropsychologia, 51(11), 2305–2317. https://doi.org/10/f5jpwq

Au, J., Sheehan, E., Tsai, N., Duncan, G. J., Buschkuehl, M., & Jaeggi, S. M. (2015). Improving fluid intelligence with training on working memory: A meta-analysis. Psychonomic Bulletin & Review, 22(2), 366–377. https://doi.org/10.3758/s13423-014-0699-x

Baddeley, A. (1986). Working memory. Working Memory., xi, 289–xi, 289.

Baddeley, A. (2000). The episodic buffer: A new component of working memory? Trends in Cognitive Sciences, 4(11), 417–423. https://doi.org/10.1016/S1364-6613(00)01538-2

Baddeley, A. D., & Hitch, G. J. (2019). The phonological loop as a buffer store: An update. Cortex, 112, 91–106. https://doi.org/10/gmf7fx

Brown, A. L. (1982). Learning, Remembering, and Understanding. Technical Report No. 244.

Carretti, B., Caldarola, N., Tencati, C., & Cornoldi, C. (2014). Improving reading comprehension in reading and listening settings: The effect of two training programmes focusing on metacognition and working memory. British Journal of Educational Psychology, 84(2), 194–210. https://doi.org/10/gnfqnp

Cattinelli, I., Borghese, N. A., Gallucci, M., & Paulesu, E. (2013). Reading the reading brain: A new meta-analysis of functional imaging data on reading. Journal of Neurolinguistics, 26(1), 214–238. https://doi.org/10/gjsmvd

Chen, X., Ye, M., Chang, L., Chen, W., & Zhou, R. (2018). Effect of working memory updating training on retrieving symptoms of children with learning disabilities. Journal of Learning Disabilities, 51(5), 507–519. APA PsycInfo. https://doi.org/10.1177/0022219417712015

Constantinidis, C., & Klingberg, T. (2016). The neuroscience of working memory capacity and training. Nature Reviews Neuroscience, 17(7), 438–449. https://doi.org/10/f3vh5v

Cornoldi, C., Drusi, S., Tencati, C., Giofrè, D., & Mirandola, C. (2012). Problem Solving and Working Memory Updating Difficulties in a Group of Poor Comprehenders. Journal of Cognitive Education and Psychology, 11, 39–44. https://doi.org/10/gnbsdf

Dahlin, E., Neely, A. S., Larsson, A., Bäckman, L., & Nyberg, L. (2008). Transfer of Learning After Updating Training Mediated by the Striatum. Science, 320(5882), 1510–1512. https://doi.org/10/dgqj44

Dahlin, K. I. E. (2011). Effects of working memory training on reading in children with special needs. Reading and Writing, 24(4), 479–491. https://doi.org/10/bmbpjm

Daneman, M., & Carpenter, P. A. (1980). Individual differences in working memory and reading. Journal of Verbal Learning and Verbal Behavior, 19(4), 450–466. https://doi.org/10/fk6kpz

de Jong, P. F. (1998). Working memory deficits of reading disabled children. Journal of Experimental Child Psychology, 70(2), 75–96. https://doi.org/10/d4vg5g

De Simoni, C., & von Bastian, C. C. (2018). Working memory updating and binding training: Bayesian evidence supporting the absence of transfer. Journal of Experimental Psychology: General, 147(6), 829–858. https://doi.org/10.1037/xge0000453

Engel de Abreu, P. M. J., Gathercole, S. E., & Martin, R. (2011). Disentangling the relationship between working memory and language: The roles of short-term storage and cognitive control. Learning and Individual Differences, 21(5), 569–574. https://doi.org/10.1016/j.lindif.2011.06.002

Engle, R. W. (2002). Working Memory Capacity as Executive Attention. Current Directions in Psychological Science, 11(1), 19–23. https://doi.org/10/b5qkt3

Engle, R. W., Kane, M. J., & Tuholski, S. W. (1999). Individual Differences in Working Memory Capacity and What They Tell Us About Controlled Attention, General Fluid Intelligence, and Functions of the Prefrontal Cortex. In A. Miyake & P. Shah (Eds.), Models of Working Memory (1st ed., pp. 102–134). Cambridge University Press. https://doi.org/10.1017/CBO9781139174909.007

Garcia, R. B., Tomaino, A., & Cornoldi, C. (2019). Cross-modal working memory binding and learning of visual-phonological associations in children with reading difficulties. Child Neuropsychology: A Journal on Normal and Abnormal Development in Childhood and Adolescence, 25(8), 1063–1083. https://doi.org/10/gncx59

García-Madruga, J. A., Gómez-Veiga, I., & Vila, J. Ó. (2016). Executive Functions and the Improvement of Thinking Abilities: The Intervention in Reading Comprehension. Frontiers in Psychology, 7, 58. https://doi.org/10/gf4xws

Gathercole, S. E., Alloway, T. P., Willis, C., & Adams, A.-M. (2006). Working memory in children with reading disabilities. Journal of Experimental Child Psychology, 93(3), 265–281. https://doi.org/10/b59c23

Gathercole, S. E., Dunning, D. L., Holmes, J., & Norris, D. (2019). Working memory training involves learning new skills. Journal of Memory and Language, 105, 19–42. https://doi.org/10/gfv5zs

Gough, P. B., & Tunmer, W. E. (1986). Decoding, Reading, and Reading Disability. Remedial and Special Education, 7(1), 6–10. https://doi.org/10/b7kc8f

Gray, S. A., Chaban, P., Martinussen, R., Goldberg, R., Gotlieb, H., Kronitz, R., Hockenberry, M., & Tannock, R. (2012). Effects of a computerized working memory training program on working memory, attention, and academics in adolescents with severe LD and comorbid ADHD: a randomized controlled trial. Journal of Child Psychology and Psychiatry, 53(12), 1277–1284. APA PsycInfo. https://doi.org/10.1111/j.1469-7610.2012.02592.x

Gropper, R. J., Gotlieb, H., Kronitz, R., & Tannock, R. (2014). Working memory training in college students with ADHD or LD. Journal of Attention Disorders, 18(4), 331–345. APA PsycInfo. https://doi.org/10.1177/1087054713516490

Holmes, J., Adams, J. W., & Hamilton, C. J. (2008). The relationship between visuospatial sketchpad capacity and children's mathematical skills. European Journal of Cognitive Psychology, 20(2), 272–289. https://doi.org/10.1080/09541440701612702

Holmes, J., & Gathercole, S. E. (2014). Taking working memory training from the laboratory into schools. Educational Psychology, 34(4), 440–450. https://doi.org/10/gh2xm8

Holmes, J., Gathercole, S. E., & Dunning, D. L. (2009). Adaptive training leads to sustained enhancement of poor working memory in children. Developmental Science, 12(4), F9–F15. https://doi.org/10.1111/j.1467-7687.2009.00848.x

Jaeggi, S. M., Buschkuehl, M., Jonides, J., & Perrig, W. J. (2008). Improving fluid intelligence with training on working memory. Proceedings of the National Academy of Sciences, 105(19), 6829–6833. https://doi.org/10/cx2vf8

Jorm, A. F. (1983). Specific reading retardation and working memory: A review. British Journal of Psychology (London, England: 1953), 74 (Pt 3), 311–342. https://doi.org/10/cm3j3v

Kane, M. J., Brown, L. H., McVay, J. C., Silvia, P. J., Myin-Germeys, I., & Kwapil, T. R. (2007). For Whom the Mind Wanders, and When: An Experience-Sampling Study of Working Memory and Executive Control in Daily Life. Psychological Science, 18(7), 614–621. https://doi.org/10/cwt295

Kim, Y.-S. G. (2017). Why the Simple View of Reading Is Not Simplistic: Unpacking Component Skills of Reading Using a Direct and Indirect Effect Model of Reading (DIER). Scientific Studies of Reading, 21(4), 310–333. https://doi.org/10.1080/10888438.2017.1291643

Kintsch, W., & Welsch, D. M. (1991). The construction-integration model: A framework for studying memory for text. In Relating theory and data: Essays on human memory in honor of Bennet B. Murdock (pp. 367–385). Lawrence Erlbaum Associates, Inc.

Klingberg, T. (2010). Training and plasticity of working memory. Trends in Cognitive Sciences, 14(7), 317–324. https://doi.org/10/bmck58

Klingberg, T., Fernell, E., Olesen, P. J., Johnson, M., Gustafsson, P., Dahlström, K., Gillberg, C. G., Forssberg, H., & Westerberg, H. (2005). Computerized training of working memory in children with ADHD--a randomized, controlled trial. Journal of the American Academy of Child and Adolescent Psychiatry, 44(2), 177–186. https://doi.org/10/bpr76k

Klingberg, T., Forssberg, H., & Westerberg, H. (2002). Training of Working Memory in Children With ADHD. Journal of Clinical and Experimental Neuropsychology, 24(6), 781–791. https://doi.org/10.1076/jcen.24.6.781.8395

Koutsandréou, F., Wegner, M., Niemann, C., & Budde, H. (2016). Effects of Motor versus Cardiovascular Exercise Training on Children's Working Memory. Medicine & Science in Sports & Exercise, 48(6), 1144–1152. https://doi.org/10.1249/MSS.0000000000000869

Maehler, C., Joerns, C., & Schuchardt, K. (2019). Training Working Memory of Children with and without Dyslexia. Children, 6(3), 47. https://doi.org/10/gncx38

Maehler, C., & Schuchardt, K. (2009). Working memory functioning in children with learning disabilities: Does intelligence make a difference? Journal of Intellectual Disability Research, 53(1), 3–10. https://doi.org/10/drxsv6

Melby-Lervåg, M., & Hulme, C. (2013). Is working memory training effective? A meta-analytic review. Developmental Psychology, 49(2), 270–291. https://doi.org/10.1037/a0028228

Melby-Lervåg, M., Redick, T. S., & Hulme, C. (2016). Working Memory Training Does Not Improve Performance on Measures of Intelligence or Other Measures of "Far-transfer": Evidence From a Meta-Analytic Review. Perspectives on Psychological Science, 11(4), 512–534. https://doi.org/10.1177/1745691616635612

Menon, V. (2016). Working memory in children's math learning and its disruption in dyscalculia. Current Opinion in Behavioral Sciences, 10, 125–132. https://doi.org/10/gm97xf

Mrazek, M. D., Franklin, M. S., Phillips, D. T., Baird, B., & Schooler, J. W. (2013). Mindfulness Training Improves Working Memory Capacity and GRE Performance While Reducing Mind Wandering. Psychological Science, 24(5), 776–781. https://doi.org/10.1177/0956797612459659

O’Shaughnessy, T. E., & Swanson, H. L. (1998). Do Immediate Memory Deficits in Students with Learning Disabilities in Reading Reflect a Developmental Lag or Deficit?: A Selective Meta-Analysis of the Literature. Learning Disability Quarterly, 21(2), 123–148. https://doi.org/10.2307/1511341

Peng, P., Barnes, M., Wang, C., Wang, W., Li, S., Swanson, H. L., Dardick, W., & Tao, S. (2018). A meta-analysis on the relation between reading and working memory. Psychological Bulletin, 144(1), 48–76. https://doi.org/10.1037/bul0000124

Peng, P., & Fuchs, D. (2016). A Meta-Analysis of Working Memory Deficits in Children With Learning Difficulties: Is There a Difference Between Verbal Domain and Numerical Domain? Journal of Learning Disabilities, 49(1), 3–20. https://doi.org/10.1177/0022219414521667

Peng, P., & Fuchs, D. (2017). A Randomized Control Trial of Working Memory Training With and Without Strategy Instruction: Effects on Young Children’s Working Memory and Comprehension. Journal of Learning Disabilities, 50(1), 62–80. https://doi.org/10/f9g2xh

Pham, A. V., & Hasson, R. M. (2014). Verbal and Visuospatial Working Memory as Predictors of Children’s Reading Ability. Archives of Clinical Neuropsychology, 29(5), 467–477. https://doi.org/10.1093/arclin/acu024

Savage, R., Lavers, N., & Pillay, V. (2007). Working Memory and Reading Difficulties: What We Know and What We Don’t Know About the Relationship. Educational Psychology Review, 19(2), 185–221. https://doi.org/10/bzq6zt

Shinaver, C. S., Entwistle, P. C., & Söderqvist, S. (2014). Cogmed WM Training: Reviewing the Reviews. Applied Neuropsychology: Child, 3(3), 163–172. https://doi.org/10.1080/21622965.2013.875314

Shipstead, Z., Hicks, K. L., & Engle, R. W. (2012). Cogmed working memory training: Does the evidence support the claims? Journal of Applied Research in Memory and Cognition, 1(3), 185–193. https://doi.org/10/ghsbsv

Shipstead, Z., Redick, T. S., & Engle, R. W. (2012). Is working memory training effective? Psychological Bulletin, 138(4), 628–654. https://doi.org/10/f3369h

Shiran, A., & Breznitz, Z. (2011). The effect of cognitive training on recall range and speed of information processing in the working memory of dyslexic and skilled readers. Journal of Neurolinguistics, 24(5), 524–537. APA PsycInfo. https://doi.org/10.1016/j.jneuroling.2010.12.001

Simons, D. J., Boot, W. R., Charness, N., Gathercole, S. E., Chabris, C. F., Hambrick, D. Z., & Stine-Morrow, E. A. L. (2016). Do “Brain-Training” Programs Work? Psychological Science in the Public Interest, 17(3), 103–186. https://doi.org/10.1177/1529100616661983

Snowling, M. J. (2013). Early identification and interventions for dyslexia: A contemporary view. Journal of Research in Special Educational Needs : JORSEN, 13(1), 7–14. https://doi.org/10/gf7dcg

Söderqvist, S., & Bergman Nutley, S. (2015). Working Memory Training is Associated with Long Term Attainments in Math and Reading. Frontiers in Psychology, 6, 1711. https://doi.org/10/f7zq5j

St Clair□Thompson, H., Stevens, R., Hunt, A., & Bolder, E. (2010). Improving children’s working memory and classroom performance. Educational Psychology, 30(2), 203–219. https://doi.org/10/fc49df

Swan, D., & Goswami, U. (1997). Picture Naming Deficits in Developmental Dyslexia: The Phonological Representations Hypothesis. Brain and Language, 56(3), 334–353. https://doi.org/10.1006/brln.1997.1855

Swanson, H. L. (2006). Cross-sectional and incremental changes in working memory and mathematical problem solving. Journal of Educational Psychology, 98(2), 265–281. https://doi.org/10/djqtng

Swanson, H. L., & Jerman, O. (2007). The influence of working memory on reading growth in subgroups of children with reading disabilities. Journal of Experimental Child Psychology, 96(4), 249–283. https://doi.org/10.1016/j.jecp.2006.12.004

Swanson, H. L., Kehler, P., & Jerman, O. (2010). Working memory, strategy knowledge, and strategy instruction in children with reading disabilities. Journal of Learning Disabilities, 43(1), 24–47. APA PsycInfo. https://doi.org/10.1177/0022219409338743

Swanson, H. L., & Siegel, L. (2011). Learning disabilities as a working memory deficit. Experimental Psychology, 49(1), 5–28.

Swanson, H. L., Xinhua Zheng, null, & Jerman, O. (2009). Working memory, short-term memory, and reading disabilities: A selective meta-analysis of the literature. Journal of Learning Disabilities, 42(3), 260–287. https://doi.org/10/chf3pr

Titz, C., & Karbach, J. (2014). Working memory and executive functions: Effects of training on academic achievement. Psychological Research, 78(6), 852–868. https://doi.org/10/f6ph5z

Toffalini, E., Marsura, M., Garcia, R. B., & Cornoldi, C. (2019). A Cross-Modal Working Memory Binding Span Deficit in Reading Disability. Journal of Learning Disabilities, 52(2), 99–108. https://doi.org/10/gh5w2j

Turley-Ames, K. J., & Whitfield, M. M. (2003). Strategy training and working memory task performance. Journal of Memory and Language, 49(4), 446–468. https://doi.org/10/bz27w8

Unsworth, N., & Spillers, G. J. (2010). Working memory capacity: Attention control, secondary memory, or both? A direct test of the dual-component model. Journal of Memory and Language, 62(4), 392–406. https://doi.org/10/bnbft5

van den Broek, P., & Espin, C. A. (2012). Connecting Cognitive Theory and Assessment: Measuring Individual Differences in Reading Comprehension. School Psychology Review, 41(3), 315–325. https://doi.org/10/gnkz8f

von Bastian, C. C., & Oberauer, K. (2014). Effects and mechanisms of working memory training: A review. Psychological Research, 78(6), 803–820. https://doi.org/10/f6pjfn

Wang, J., Wu, K. C., Mo, J., Wong, W. L., Siu, T. S. C., McBride, C., Chung, K. K. H., Wong, P. C. M., & Maurer, U. (2021). Remediation of a phonological representation deficit in Chinese children with dyslexia: A comparison between metalinguistic training and working memory training. Developmental Science, 24(3), e13065. https://doi.org/10/gnczh6

Wang, J.-R., & Hsieh, S. (2013). Neurofeedback training improves attention and working memory performance. Clinical Neurophysiology, 124(12), 2406–2420. https://doi.org/10.1016/j.clinph.2013.05.020

Woods, D. L., Kishiyama, M. M., Yund, E. W., Herron, T. J., Edwards, B., Poliva, O., Hink, R. F., & Reed, B. (2011). Improving digit span assessment of short-term verbal memory. Journal of Clinical and Experimental Neuropsychology, 33(1), 101–111. https://doi.org/10.1080/13803395.2010.493149

Yang, J., Peng, J., Zhang, D., Zheng, L., & Mo, L. (2017). Specific effects of working memory training on the reading skills of Chinese children with developmental dyslexia. PLoS ONE, 12(11). APA PsycInfo. https://doi.org/10.1371/journal.pone.0186114

Zhang, H., Chang, L., Chen, X., Ma, L., & Zhou, R. (2018). Working memory updating training improves mathematics performance in middle school students with learning difficulties. Frontiers in Human Neuroscience, 12. APA PsycInfo. https://doi.org/10.3389/fnhum.2018.00154